Optical Link Fault Detection In Optical Link And Localization In Passive Optical network Domain

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ABSTRACT: Optical link fault detection and localization are significant in the Passive optical network (PON) due to the passive nature of the network elements involved. A single failure in the optical link can resort to a huge amount of data loss in the network. However, deployment of fault detection and localization devices is extremely limited due to the extra cost network operators need to pay and the reliability of the devices. PON fault monitoring solutions have been investigated by the researchers over the decades; the challenges for these monitoring techniques are the cost and complexity of their deployment. Thus, this work proposes a technique for the detection and localization of fault in the optical link of a PON Fiber-to-the-x (FTTx) network using optical reflectors. The real-time back-reflected signal from the reflectors in the network will be utilized to determine the optical link with fault. Experimental results obtained show that multiple optical link impairments can be detected and localized in the PON FTTx based network in-service, over a distance of 20 km, in a cost-effective manner. Measurements from a standard Optical Time-Domain Reflectometer (OTDR) is used to prove the validity of our technique.

KEYWORDS: Fault monitoring, PON, FTTx

1 INTRODUCTION

Presently, high-speed data transmission is exponentially increasing due to the high demand for internet connectivity of a majority of people across the globe. Triple play services, video on demand, e-learning, e-health, e-governance, cloud computing, e-books, smart systems, and online entertainment are examples of the key drivers that will spur the growing demands for high bandwidth broadband access network. It is clear that access to the internet via copper lines had reached its limits, and the only hope for increased bandwidth in the near future is through the installation of optical fiber . The broadband services in fiberoptic networks not only provide high-speed internet services with large bandwidth but also the most energy-efficient access network when deployed using passive optical network (PON) technology (Ramli, Zulkifli, Usman, & Idrus, 2018). PON is considered the most promising candidate for optical access network (OAN) that provides high-speed data transmission rate at a lower infrastructure cost (Nesset, 2017). When implemented in point-to- multipoint (P2MP) fiber-to-the-x (FTTx) architecture, PON appears to be the utmost solution for the future last- mile bottleneck, a shared fiber carries the data traffic from the central office (CO) to the passive splitting unit at a point very close to the customer's end (Bindhaiq et al., 2015). Consequently, there is no need to deploy a single dedicated fiber from the CO to the individual customer premises. Important FTTx deployments have been accomplished across the globe over the two decades .

For service providers, whilst the large-scale adoption of FTTx technology presents enormous bandwidth growth opportunities, at the same time it also poses significant challenges. The challenges include limitations in the existing optical link fault detection and location devices. FTTx fiber plant requires an automated fault management mechanism to ensure system reliability and maintenance purposes. Several fault monitoring solutions for optical fiber fault management are investigated and proposed over the decades. The main drawbacks of these devices and techniques are the high cost and complexity of their deployments. In this paper, an optical link fault detection and location model for the P2MP network are proposed, where an experimental demonstration of optical fiber fault detection and localization in a 1x4 PON FTTx system is demonstrated. The reflective based monitoring method is employed using an optical reflector where the reflected signals are received and analyzed in the CO to obtain the fiber fault position in the various distribution link of the network. In section two of the article, a review of related studies is presented, section three presents the methodology and experimental setup, section four presents the results and findings, and lastly, in section five, we present the conclusions and future work.

2 REVIEW OF RELATEDWORK

Optical link fault detection and localization in optical access networks were for over the decades being conducted using optical time-domain reflectometer (OTDR) based technique (Solution, 2016), as outlined in the ITU-T L.40 standard for optical fiber cable maintenance support, testing, and monitoring. However, the OTDR tool is only suitable to characterize optical link in point-to-point (P2P) network but inefficient to monitor fiber fault in the P2MP network, due to multiple reflected/backscattered signals from different fiber branches. In order to solve this issue, researchers have proposed several modified versions of OTDR that includes the application of tunable OTDR (T-OTDR) (Amaral et al., 2014; Herrera, Amaral, & Weid, 2017). In the T-OTDR technique, all the fiber branches are successively identified using the T-OTDR where the status of each fiber link is obtained one by one by the T-OTDR. Although the technique can detect and locate a fault in the P2MP network, the solution is expensive due to special tunable lasers and limited network size. The chaotic OTDR (C-OTDR) utilizes a laser diode with optical fiber ring feedback to generate a chaotic laser light which is used as a probe signal to detect and locate fiber faults (Hu et al.,; Wang, Wang, & Wang, 2008). Besides, the embedded OTDR that constitutes a mini OTDR integrated into the optical network units (ONUs) to measure the back-reflected signal has also been proposed in (Caballero, Herrera, Weid, & Urban, 2017; Devicharan, Zahnley, Dahl, Gurusami, & McClean, 2015; Urban, Vall-llosera, Medeiros, & Dahl fort, 2013). The monitoring signal and data transmitted signal in this technique are time slotted which creates a delay in data signal transmission and limits the effective data bandwidth.

3 METHODOLOGY/MATERIALS

3.1 Theoretical background

In the transmission and reception of an optical signal as shown in figure 1, when an optical signal from the optical source with a lunched power Po is applied into the optical network through an optical circulator (CIR) to the feeder fiber (FF), a transmitted power (P_T) can be obtained at the fiber's termination point (customers end). Similarly, the backscattered power (P_B) which occurs as a result of Rayleigh backscattering through the fiber,

can be obtained at the input of the optical fiber. When a fault occurs along with the optical link that induces a degradation in the optical power, the relationship between the variable's P_T and P_B will depend on the fault location. Therefore, the event type can be localized by obtaining P_B and P_T. The localization of fault in the optical link depends on the distinctive relationship between P_T and P_B for a given event location and the return loss (R_L) (Spirin et al., 2004).

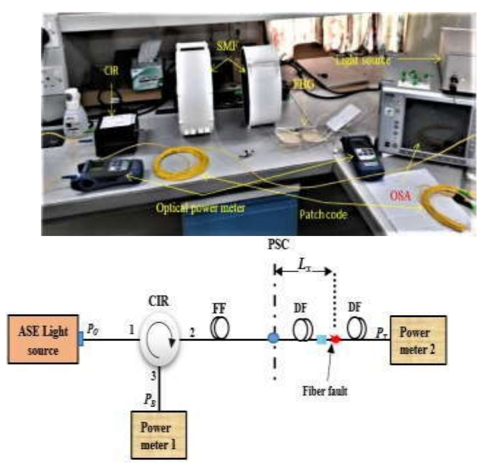


Figure 1. Fault localization in optical link setup (a) snap shot of the experimental test-bed (b) schematic arrangement for fault localization method

Let's the position of power splitter/combiner (PSC) be a demarcation point between FF and the DF section as shown in figure 1 (b), the fault position in the DF reflects the probe pulses with an R_L. When the monitoring pulses passes through the optical link, we can theoretically obtain the corresponding P_B. However, the optical link and the optical CIR attenuate the probe pulse as a result of the fiber loss and CIR insertion loss (I_L). Therefore, the optical fiber transmission coefficient, T in relation to the fiber attenuation coefficient α is given where λ is the radiation wavelength, n_1 is the refractive index at the center of the core, ω_0 is the mode field radius. The total backscattered/reflected power P_{Bi} in an initially undisturbed system (considering the directivity of the CIR) can be obtained as (Spirin et al., 2004).

The experimental arrangement of the proposed system is illustrated in figure 2, amplified spontaneous emission (ASE) broadband optical source is used as the probe signal at the CO. The probe pulse and data signal are multiplexed and transmitted into the network through a 3-port CIR. The optical reflectors are placed at the remote node (RN) in the customer's end.

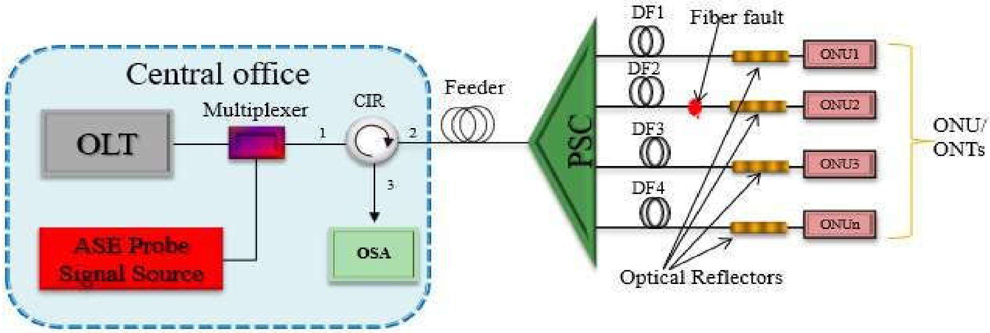


Figure 2. Proposed Optical Reflective based PON monitoring System in the FTTx network.

The reflectors can be an optical mirror, a fiber Bragg grating (FBG) or any optical reflector that can reflect the probe pulses. Each Drop fiber (DF) link in the 1x4 FTTx PON has a reflector placed at the point very close to the customer premises which is considered more vulnerable to risk. The corresponding Bragg wavelength and reflectivity of the reflectors used in our experiment and other materials used are listed in table 1. The reflected probe signal is received at port 3 of the CIR and examined by an optical spectrum analyzer (OSA) to detect the faultylink.

Table 1: Experimental equipment specifications

Equipment	Specification
Spooloffiber	20 kmSMF
Patchcable	10 m and 2m
FBGreflector	(1540.5, 1544.04, 1549.805, 1552.9) nm at Reflectivity > 95.59%
3-Port OpticalCirculator	C-band
OpticalSpectrumAnalyzer	MS9740A
Opticalsource	ASE
Opticalpowermeter	NESTONGT1102
OpticalTimeDomain Reflectometer	ANRITSUMT9083

4 RESULTS AND FINDINGS

The probe signal is generated from the ASE laser source, the output of the optical source is shown in figure 3. When the ASE probe signal is launched into the 1x4 PON FTTx network through a CIR, the reflectors set at the RN will reflect the probe signal. The reflected signals spectra will be observed simultaneously at the OLT side in the CO. In order to observe the reflected signal from the monitoring elements, an OSA at 0.03 nm resolution is used. In the measurement, the passive components of single-mode fiber (SMF), CIR, and PSC would

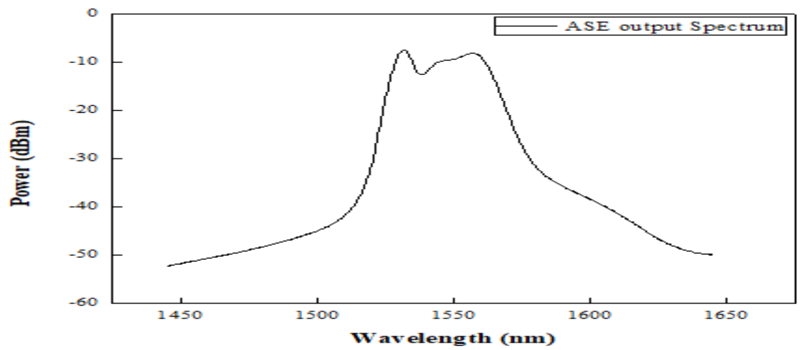
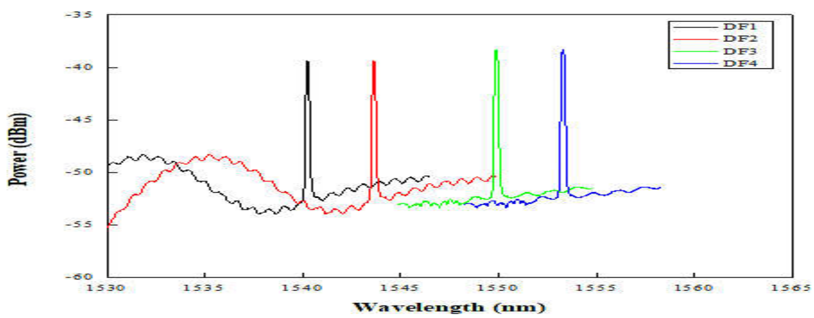


Figure 3. ASE Optical source output signal spectrum



result in the corresponding I_L of 0.2 dB/km, 1 dB, and 7 dB respectively. Figure 4 shows the measured OSA signal spectra of the reflected probe pulses without fault events along the optical link. Meanwhile, in the event of fiber fault introduced at the DF link 2 as shown in figure 5, the signal spectrum of the reflector 2 at the DF2 is significantly reduced indicating loss of signal, which clearly shows a fiber fault at the particular opticallink.

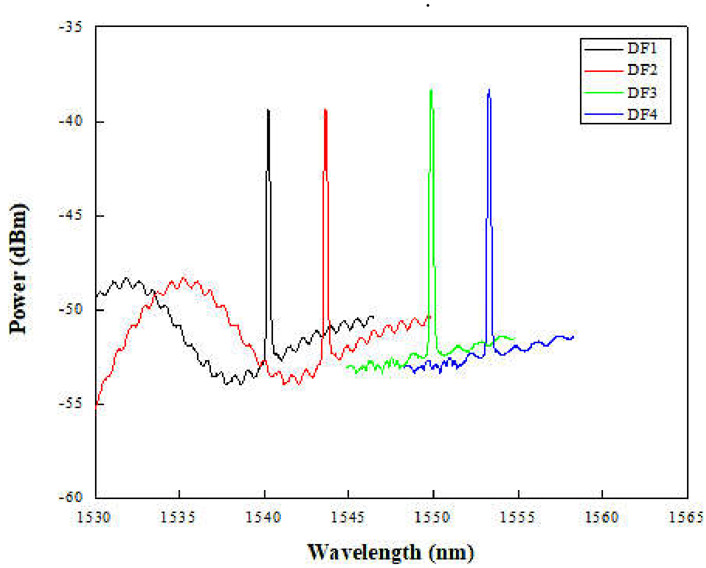


Figure 4. Output signal spectra of the reflected signal under no-fault condition

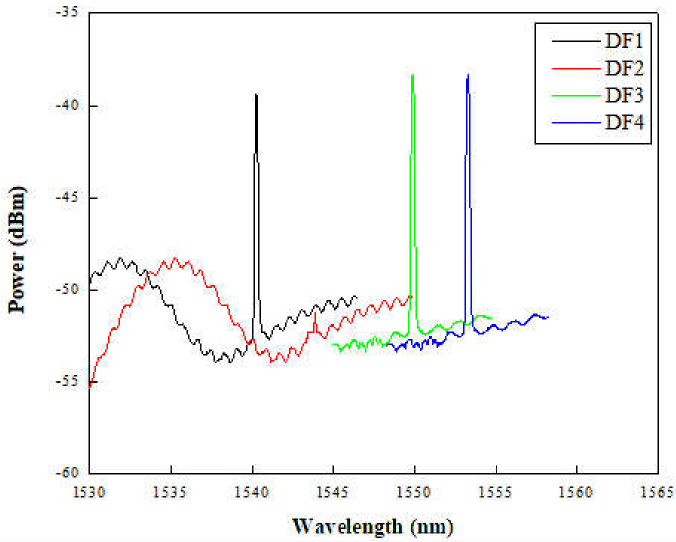


Figure 5. Signal spectra of the reflected monitoring signal under fault condition.

In order to locate the fiber fault position after detecting the faulty optical link, a measurement was conducted using optical power meter at the CIR port 3 and the fiber end, to obtain the corresponding values of total backscattered/reflected power with and without fault event in the optical link. These values and other parameters listed in table 2 are used to solve for Lx in equation (6), which is the approximated fault position in the optical link. The calculated and measured optical link fault position is shown in table 3.

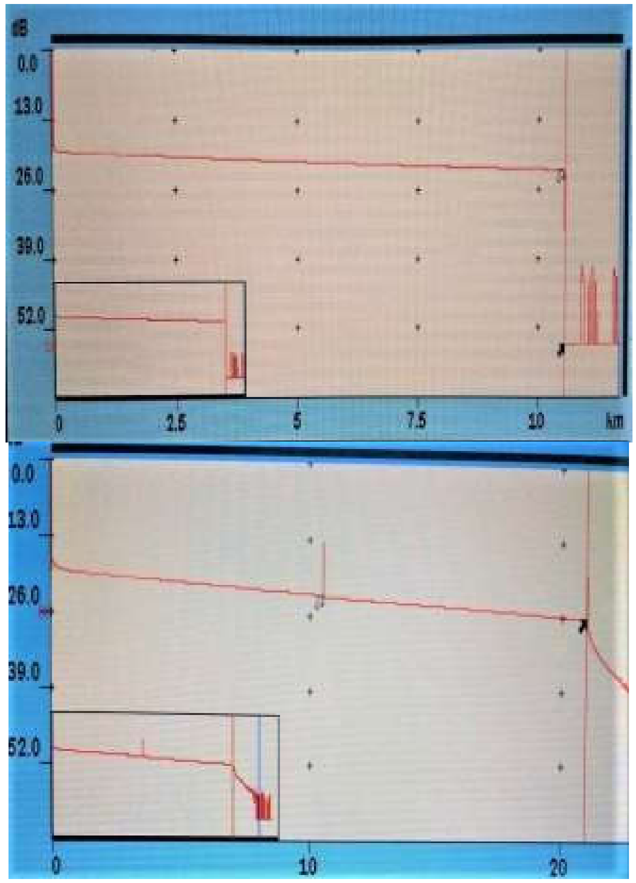
Table 2: Parameters used for the calculation of optical link fault location

Wavelength (nm)	Distance L	$\mathbf{P_O}$(mw)	$\mathbf{P_{Bi}}$(mw)	$\mathbf{P_{Bo}}$(mw)	**DIR**	**α**(dB/km)	$\mathbf{S_c \cdot \alpha_{(s)}}$
1550	20 km	2.68	1.737	0.933	> 50	0.23	0.0026

OTDR test was conducted to compare the performance of the proposed method. In the experiment, an OTDR pulse is injected into the detected faulty optical link, the OTDR is set at 1550 nm wavelength with a dynamic range of 25 km at 1.001 m resolution, and a pulse width of 200 ns. The OTDR trace for the measurement is shown in figure 6, and the result is shown in table 3. It can be observed that from the result of the measured value and calculated value, the proposed method has an error of approximately1.7%.

Table 3: Results for Measured value and Calculated value for optical link fault location at 1550 nm

	Distance L_x (m)	Difference in (m)	% error
OTDR meas. Value	10558.4	-183.3	-1.74
Calculated value	10742.7	183.3	1.74



(a) (b)

Figure 6. OTDR traces for optical link fault location (a) with and (b) without fault.

5 CONCLUSION AND FUTUREOUTLOOK

An experimental method for optical fiber fault detection and localization in the PON FTTx network using optical reflectors is proposed. The technique utilizes optical reflectors for failure detection and location in the optical fiber link, the monitors are placed at the last mile of the network very close to the user's end, which is considered more vulnerable to risk in the network. The reflected signals spectra from the reflectors are observed at the CO to detect and locate the fiber link with the fault in the network. Result obtained shows the technical ability to detect and locate a fault in a 1x4 FTTx PON network at a distance of 20 km. A standard OTDR test is conducted to ascertain the integrity of the proposed method. However, the result obtained from the proposed method shows 98% accuracy compared to the OTDR measurement, therefore an improved measurement with an optical power meter at higher measurement resolution can effectively improve the monitoring accuracy of the technique.

6 ACKNOWLEDGEMENT:

The authors acknowledge the Ministry of Higher Education (MOHE) Malaysia and Research Management Centre, UTM for the financial support through the Transdisciplinary Research Grant (TDR) GUP T1, vote number 05G60 and Fundamental Research Grant Scheme, FRGS vote number 5F086. We are also grateful for the TETFUND scholarship from the Federal Government of Nigeria to the first author.

7 REFERENCES

[1] Amaral, G. C., Herrera, L. E. Y., Vitoreti, D., Temporao, G. P., Urban, P. J., &von der Weid, J. P. (2014). WDM-PON Monitoring With Tunable Photon Counting OTDR. IEEE Photonics Technology Letters, 26(13), 1279-1282.doi:10.1109/lpt.2014.2320871

[2] Bindhaiq, S., Supa׳at, A. S. M., Zulkifli, N., Mohammad, A. B., Shaddad, R. Q., Elmagzoub, M. A., & Faisal, A. (2015). Recent development on time and wavelength-division multiplexed passive optical network (TWDM-PON) for next-generation passive optical network stage 2 (NG-PON2). Optical Switching and Networking, 15, 53-66.doi:10.1016/j.osn.2014.06.007

[3] Caballero, D. V., Herrera, L. E. Y., Weid, J. P. v. d., & Urban, P. J. (2013, 27-30 Aug. 2013). Low-cost embedded OTDR monitoring for direct modulation analog radio over fiber. Paper presented at the 2017 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference(IMOC).

[4] Devicharan, D., Zahnley, T., Dahl, S., Gurusami, A., & McClean, I. (2015, 22-26 March 2015). Low optical power embedded OTDR. Paper presented at the 2015 Optical Fiber Communications Conference and Exhibition(OFC).

[5] Esmail, M. A., & Fathallah, H. (2013). Physical Layer Monitoring Techniques for TDM-Passive Optical Networks: A Survey. IEEE Communications Surveys & Tutorials, 15(2), 943-958. doi:10.1109/surv.2012.060912.00057

[6] Fouli, K., Chen, L. R., & Maier, M. (2011). Time-, wavelength-, and code-domain optical reflection monitoring for next-generation access-metro networks. Computer Communications, 34(8), 1011-1021. doi:https://doi.org/10.1016/j.comcom.2010.11.005

[7] Hayashi, N., Mizuno, Y., & Nakamura, K. (2014). Distributed Brillouin Sensing With Centimeter-Order Spatial Resolution in Polymer Optical Fibers. Journal of Lightwave Technology, 32(21), 3999-4003. doi:10.1109/jlt.2014.2339361

[8] Herrera, L. E. Y., Amaral, G. C., & Weid, J. P. v. d. (2011, 2011). Remote fiber Bragg grating-based sensor characterization with ultra-high-resolution tunable photon counting OTDR. Paper presented at the 2017 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference(IMOC).

[9] Nesset,D.(2017).PONRoadmap[Invited].JournalofOpticalCommunicationsandNetworking,9(1), A71-A76. doi:10.1364/JOCN.9.000A71

[10] Ramli, A., Zulkifli, N., Usman, A., & Idrus, S. M. (2013). A development of optical network unit power consumption model considering traffic load effect. Jurnal Teknologi, 80(4), 17-22. doi:https://doi.org/10.11113/jt.v80.10247

[11] Solution, V. (2016). t-berd-mts-8000-scalable-multitest-platform-product-solution-briefs-en.pdf User manual. VIAVI SolutionsInc.

[12] Spirin, V. V., Mendieta, F. J., Miridonov, S. V., Shlyagin, M. G., Chtcherbakov, A. A., & Swart, P. L. (2004). Localization ofa loss-inducing perturbation with variable accuracy along a test fiber using transmission-reflection analysis. IEEE Photonics Technology Letters, 16(2), 569-571. doi:10.1109/LPT.2003.821048